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**Vikings, peat formation and settlement abandonment: a multi-method
chronological approach from Shetland**

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28 **Abstract**

29 Understanding the chronology of Norse settlement is crucial for deciphering the archaeology of
30 many sites across the North Atlantic region and developing a timeline of human-environment
31 interactions. There is ambiguity in the chronology of settlements in areas such as the Northern Isles
32 of Scotland, arising from the lack of published sites that have been scientifically dated, the presence
33 of plateaus in the radiocarbon calibration curve, and the use of inappropriate samples for dating.
34 This novel study uses four absolute dating techniques (AMS radiocarbon, tephrochronology,
35 spheroidal carbonaceous particles and archaeomagnetism) to date a Norse house (the “Upper
36 House”), Underhoull, Unst, Shetland Isles and to interpret the chronology of settlement and peat
37 which envelops the site. Dates were produced from hearths, activity surfaces within the structure,
38 and peat accumulations adjacent to and above the structure. Stratigraphic evidence was used to
39 assess sequences of dates within a Bayesian framework, constraining the chronology for the site as
40 well as providing modelled estimates for key events in its life, namely the use, modification and
41 abandonment of the settlement. The majority of the absolute dating methods produced consistent
42 and coherent datasets. The overall results show that occupation at the site was not a short, single
43 phase, as suggested initially from the excavated remains, but instead a settlement that continued
44 throughout the Norse period. The occupants of the site built the longhouse in a location adjacent to
45 an active peatland, and continued to live there despite the encroachment of peat onto its margins.
46 We estimate that the Underhoull longhouse was constructed in the period *cal. AD 805–1050* (95%
47 probability), and probably in *cal. AD 880–1000* (68% probability). Activity within the house ceased
48 in the period *cal. AD 1230–1495* (95% probability), and most probably in *cal. AD 1260–1380* (68%
49 probability). The Upper House at Underhoull provides important context to the expansion and
50 abandonment of Norse settlement across the wider North Atlantic region.

51

52

53

54 **1. Introduction**

55 The overall aim of this paper is to establish a multi-method chronology of settlement and
56 environment changes at the site of Underhoull in Unst, Shetland Isles. This is important for both
57 Quaternary science and global environmental change research because it typifies the challenges of
58 dating the Viking Age-Medieval Scandinavian colonisation of the North Atlantic islands. The term
59 ‘Viking’ usually refers to raiding activity and the initial territorial expansion of Scandinavian
60 peoples from the last decades of 8th century to the 11th century, whereas ‘Norse’ covers the whole
61 cultural period from first settlement to the mid-15th century in the Northern Isles when the islands
62 were ceded to the Scottish crown (Batey and Sheehan, 2000). This movement of people involved
63 the migration into, and enduring occupation of, both long settled-lands in Atlantic Scotland and
64 mid-oceanic islands that were some of the last places on Earth to be colonised by people. The
65 former provide instructive cases of culture contact, the latter provide recent case studies of the
66 impact of people on pristine environments with clear pre-human environmental baselines. Both
67 provide ‘completed experiments’ of human interactions with the environment during the Medieval
68 Climate Anomaly (a time of warm climate lasting from ~AD 950 to AD 1250) in NW Europe
69 (Goosse et al., 2012) that are relevant to contemporary debates about global change that include
70 societal resilience, the basis of sustainability over multi-century time scales, causes of human
71 insecurity, climate change adaptation and the limits to adaptation (e.g. Nelson et al., 2016).

72
73 Increasing attention has been paid to the study of Norse sites across the North Atlantic and the
74 Distributed Long-Term Observing Network of the Past (DONOP) that they provide (Hambrecht et
75 al., 2018). The investigation of DONOP has involved archaeological excavation and related multi-
76 proxy environmental studies which can be used to address Grand Challenges in archaeology,
77 including questions of 1) societal resilience, persistence and collapse; 2) the movement, mobility
78 and migration of people, and 3) human environment interactions (Kintigh et al., 2014). The drivers
79 of the Scandinavian migrations and the expansion of the Viking Age settlements across this region

80 have been attributed to a variety of factors, such as stresses of population change (Fossier, 1999),
81 climate (Dugmore et al., 2007), economic factors and political tension (Frei et al., 2015; Pálsson
82 and Edwards 1981; Sawyer, 2003), while similar theories have been postulated for the abandonment
83 of Norse settlements in Greenland (Dugmore et al., 2012). An accurate and precise chronology is
84 essential for the assessment of specific Norse sites and their utilisation as DONOP to allow the
85 archaeological evidence to be directly compared and understood across this vast geographical area,
86 and be mobilised to address Grand Challenges (Kintigh et al., 2014, Nelson et al., 2016).

87

88 Over the last 30 years, the chronological assessment of Norse sites across the North Atlantic realm
89 have made widespread use of radiocarbon or in the case of Iceland, radiocarbon and the use of
90 visible tephra layers (e.g. Barrett et al., 2000; Dugmore et al., 2005; Arge et al., 2005; Lawson et al.,
91 2005; Church et al., 2005; 2007; Schmid et al., 2017). However, many existing chronological
92 frameworks have significant limitations due to a primary reliance on artefact and structural
93 typologies (e.g. Hamilton, 1956; Small, 1966; Stummann Hansen, 2000) or on scientific dating
94 approaches that utilise inappropriate materials, including non-native species such as Spruce (*Picea*)
95 or mixtures of materials. In Iceland, classic tephrochronology, based on the identification and
96 correlation of layers of volcanic ash (tephra), is a very powerful dating tool for establishing a robust
97 chronology for the Viking Age settlement. The utility and accuracy of classic tephrochronology
98 stems from the very widespread distribution of the Landnám tephra as a visible layer, and the
99 extensive occurrence of a series of other visible tephra layers within the 10th century, such as the
100 Katla c. AD 920 tephra and the Eldgjá tephra from AD 939 (Schmid et al., 2017). The great
101 precision of classic tephrochronology in Viking Age Iceland is because two of these crucial layers-
102 the Landnám tephra and the Eldgjá tephra- have been traced to Greenland and dated in ice core
103 records (Grönvold et al., 1995; Zielinski et al., 1995, 1997; Sigl et al., 2015; Schmid et al., 2017).
104 While the use of visible tephra layers is routine in Icelandic archaeology, the use of cryptotephra in
105 archaeological sites elsewhere in the North Atlantic is not, despite their discovery in terrestrial

106 Scottish peat deposits 30 years ago (Dugmore 1989, Dugmore et al., 1995a; 1995b). This represents
107 significant opportunity for archaeology, because of the continental scale dispersal of the tephras as
108 crypto deposits, and their very precise dating- either through connections with ice cores, or through
109 contemporary written sources, such as the dating of Hekla eruptions to AD 1104 and AD 1158.

110

111 Cryptotephrochronology is making vital contributions to the precise correlation of long-term proxy
112 records of Quaternary environments (e.g. Davies, 2015; Lane et al., 2012). The great potential for
113 the use of cryptotephras in archaeology and correlating archaeological DONOP (e.g. Lane et al.,
114 2014) is largely untapped. As its potential is realised, an effective integration of
115 cryptotephrochronology with other Quaternary dating techniques presents particularly interesting
116 opportunities. Thus, we present an integrated chronology for the establishment, use and
117 abandonment of a peat-covered Norse longhouse at the site of Underhoull, Shetland, UK
118 (60.71888°N, 0.94735°W) using the novel combination of radiocarbon, cryptotephra, spheroidal
119 carbonaceous particles and archaeomagnetic dating. We critically assess and compare these
120 techniques within a Bayesian framework in order to produce a robust chronology for the site. We
121 address the following research questions: 1. When was the site occupied and then subsequently
122 abandoned? 2. What is the chronostratigraphic relationship between the longhouse and peat
123 accumulation? The answers to these questions contribute significantly to evaluation of Norse
124 settlement in Shetland and demonstrate methodologies applicable across Northwest Europe and
125 North America.

126

127 **2. Study site selection and context**

128 Archaeological sites in Shetland, such as Old Scatness (Dockrill et al., 2010), Norwick (Ballin
129 Smith, 2007), Hamar and Underhoull (Bond et al., 2013) form a DONOP and provide a window
130 into the culturally turbulent Viking Age, set within the equable conditions of the Medieval Climate
131 Anomaly.

132 The site of Underhoull is located on Unst, the most northerly of the Shetland Isles, and of Britain
133 (Figure 1). Unst is particularly significant because it may have played an important role in the
134 westwards expansion of the Viking/Norse populations, acting as a staging post between Norway,
135 Britain and the islands further west (Ritchie, 1996; Graham-Campbell and Batey, 1998). Recent
136 discoveries have produced early dates for Scandinavian settlement in the Northern Isles (Orkney
137 and Shetland), which have important implications for understanding the timing, pace and nature of
138 the westward migrations of the Viking Age. The site of Norwick, for example, now has evidence
139 for an early phase of Scandinavian settlement in the 7th–9th centuries AD (Ballin Smith, 2007). If
140 the pattern from Norwick is replicated elsewhere, it would stretch the chronology of westward
141 Norse expansion earlier, and modify ideas of its development and consequences.

142

143 A large number of Norse longhouses have been recorded on Unst, with Dyer et al. (2013)
144 identifying some 30 individual sites, together with another 20 possible longhouses. This implies
145 that the island played a very significant role in the westwards expansion of the Norse. Despite this
146 significance, only a small number of Norse sites have been investigated to date, including Sandwick
147 (Bigelow, 1985), Underhoull (Small, 1966), Norwick (Ballin Smith, 2007), Hamar (Bond et al.,
148 2013) and Belmont (Larsen et al., 2013). At Underhoull, Small (1966) recorded a Norse structure
149 that sealed an Iron Age roundhouse and souterrain, demonstrating one of many Shetlandic examples
150 of site continuity linked to transformative cultural changes (Figure 2). A 10th century date was
151 assigned to the Norse site following Small's work based on the artefact evidence, although a later
152 date has been suggested by a reassessment of the structural and artefact typologies (Graham-
153 Campbell and Batey, 1998). Radiometric dating evidence has been produced for the sites of
154 Sandwick, Norwick, Hamar and Belmont (Figure 1), although only the sites of Hamar and Belmont
155 have been fully published to date. The remaining published site chronologies in Shetland, such as
156 the iconic site of Jarlshof (Hamilton, 1956), are largely based on artefact typologies. While these
157 traditional approaches provide a general framework, they have limited precision. More rigorous

158 chronologies based on a wider range of approaches and scientific methodologies will provide an
159 enhanced understanding of the pattern and timing of Norse occupation of Shetland, the longevity of
160 settlement and its wider significance within the Norse diaspora.

161

162 **3. Establishing chronology: The sampled contexts**

163 The site discussed within this paper is located upslope from the excavations carried out by Small
164 (1966), and so to avoid confusion with this earlier work it will be referred to as the “Upper House”,
165 Underhoull. The Upper House site (Figure 2) consists of a longhouse with two associated annexes.
166 The addition of annexes to longhouses has been considered a characteristic feature of Late Norse
167 longhouses, recorded on sites such as Underhoull, Hamar and Belmont (Graham-Campbell and
168 Batey, 1998; Bond et al., 2013; Larsen et al., 2013), which suggests that the surviving structure at
169 Underhoull dates to the late 10th century at the earliest. Several features were recorded within the
170 structure including a paved area in the western end of the main structure and three hearths, one in
171 each of the annexes and a third in the eastern part of the main structure. An area of paving (context
172 [029]) was also identified to the south of the main structure overlying the peat, and has been
173 interpreted as an attempt by the occupants to maintain a dry area around the longhouse despite the
174 close proximity to the peat accumulations.

175

176 Understanding the formation processes is crucial in the selection of appropriate samples, as well as
177 the interpretation of the results, so the formation processes of the anthropogenic deposits are
178 summarised under the heading ‘depositional context’. A classification of deposits in terms of
179 chronological significance is derived from the work of Schiffer (1987) and Dockrill et al. (2006),
180 and is summarised in Table 1. The peat dates were not categorised using this approach due to the
181 potential mobility of the different fractions. The materials finally selected for dating formed two
182 groups: the deposits associated with the occupation of the structure, and the peat located in the

183 south-west area of the site. The dates have been summarised in Table 2 (radiocarbon), Table 3
184 (archaeomagnetic) and Table 4 (tephra).

185

186 The deposits located within the structure were dated by AMS radiocarbon and archaeomagnetic
187 dating techniques, including occupation surfaces (contexts [189] & [185]), hearths (contexts [166],
188 [214] and [201]), a surface interpreted as a yard to the north of the main structure (context [170]),
189 and a possible industrial deposit (context [093]). The peat accumulations adjacent to the longhouse
190 were sampled for cryptotephra and for AMS radiocarbon dating; the flagged surface (context [029])
191 associated with the structural remains effectively acted as a horizon dividing the peat layers into
192 those that pre- and post-dated the construction of the longhouse (Figure 3). The dating evidence
193 produced from these deposits therefore brackets this event, providing an opportunity to investigate
194 when the occupation of the Upper House commenced relative to the peat and the impact that the
195 peat development had on the occupation of Underhoull. The date of the paved surface [029] is also
196 important as it provides the upper limit for the construction of the longhouse, as well as dating an
197 attempt by the occupants to maintain the site.

198

199 **4. Materials and methods**

200 Three dating methods (AMS radiocarbon, archaeomagnetic dating and cryptotephrochronology)
201 were employed in addition to the conventional archaeological methods of stratigraphy and
202 typology. In addition to these approaches, spheroidal carbonaceous particles (SCPs) within the peat
203 were used to infer a post 19th-century date for the top of the sampled sequences (e.g. Swindles,
204 2010). All of the dates presented here are quoted at 2 sigma (σ)/95.4% confidence levels with the
205 exception of the SCPs (post-AD1850 markers) and the tephra isochrones dated to the 12th century
206 AD based on historical observation and documentary evidence. The Hekla-Selsund tephra (also
207 referred to as the Kebister tephra by Dugmore et al., 1995b) has been previously wiggle-match ¹⁴C
208 dated (Wastegård et al., 2008).

209 **4.1 AMS Radiocarbon dating**

210 AMS radiocarbon determinations (Table 2) were produced by the Scottish Universities
211 Environmental Research Centre (SUERC), and the Natural Environment Research Council (NERC)
212 Radiocarbon Facility, East Kilbride, and calibrated using OxCal v4.3 (Bronk Ramsey, 2012), with
213 IntCal13 (Reimer et al., 2013).

214

215 The materials selected for dating included charred grains of barley (*Hordeum* sp.) and *Sphagnum*
216 remains extracted from the peat (although *Sphagnum* was only found in a 5-cm horizon in one of
217 the peat monoliths), as these represent chronologically coherent entities that did not require a
218 marine correction (Harris, 1987). Barley grains represent a single entity produced in a single
219 season's growth, removing some of the problems of 'old' carbon being incorporated (Ashmore,
220 1999), and were selected from discrete contexts such as hearths, floor surfaces and a yard area. Both
221 the barley grains and *Sphagnum* leaves and stems were hand-picked from samples using tweezers
222 under a low-power binocular microscope. Above-ground macrofossils (e.g. *Sphagnum* remains)
223 were mostly not present or in low abundance in the peats, therefore the humin and humic acid
224 fractions of humified peats were extracted from discrete samples for dating.

225

226 The composition of peat varies depending on the plant communities, the accumulation rate, the
227 water-table level, bioturbation, root penetration, and the incorporation of residual material, as well
228 as any anthropogenic activity in the area (Rydin and Jeglum, 2008). It can therefore be argued that
229 no two accumulations of peat are the same, making it difficult to state with confidence which of the
230 fractions would represent the 'true' age of peat accumulation as all of these factors are site specific
231 (Tonneijck et al., 2006; Wüst et al., 2008; Brock et al., 2011). A number of radiocarbon dates were
232 produced for this study using both the humic and humin fractions from the same sample, allowing
233 these processes to be evaluated.

234

235 The charred barley grains and *Sphagnum* remains were pre-treated using the standard acid-base-acid
236 procedure for removal of carbonates and organic acids (Ascough et al., 2007). The peat humin
237 fraction was extracted through the digestion of the peat in 2M HCl (80°C, 8 hours) followed by 1M
238 KOH (80°C, 2 hours) until no further humic material was extracted. The residue was then rinsed
239 free of alkali, before being immersed in 1M HCl (80°C, 2 hours), rinsed free of acid, dried and then
240 homogenised. The peat humic acid fraction was extracted using a similar approach, but the filtrate
241 was retained and the humic fraction precipitated following the addition of 2M H₂SO₄. The
242 precipitate was recovered, rinsed free of acid, dried and homogenised (Gulliver, 2011). The pre-
243 treated remains were then converted to graphite for subsequent AMS analysis using standard
244 methods defined by Slota et al. (1987). The $\delta^{13}\text{C}$ value of the sample CO₂ was determined on a VG
245 SIRA 10 stable isotope mass spectrometer using NBS standards 22 (oil) and 19 (marble) to
246 determine the 45/44 and 46/44 mass ratios, from which a sample $\delta^{13}\text{C}$ value could be calculated
247 (Ascough et al., 2007). The $\delta^{13}\text{C}$ ratios were used to correct the sample ^{14}C activities for
248 fractionation by normalisation to -25‰ .

249

250 The potential problem of post-depositional movement of the barley grains or the mobility of the
251 different fractions of peat was investigated through the production of multiple dates analysed in
252 stratigraphic order, a comparison of paired dates produced on different fractions and by a
253 comparison between different methods.

254

255 **4.2 Archaeomagnetic dating**

256 Archaeomagnetic dating can yield significant chronological information as the dated event relates to
257 the last use of the features which usually corresponds to anthropogenic activity (Clark et al., 1988;
258 Batt et al., 2017). Three features were sampled for archaeomagnetic dating from Underhoull:
259 hearths located in each of the two annexes (contexts [166] and [214]) and a possible industrial
260 feature (context [093]) located to the North of the site (Table 3). A fourth hearth was identified

261 within the main structure (context [201]), but it did not contain sufficient material for
262 archaeomagnetic dating. Plastic tubes were inserted into the fired material using the methodology
263 defined by Clark et al. (1988). A magnetic compass was used to record the orientation of the
264 samples; this method can be problematic as the feature itself may deflect the compass, introducing
265 errors into the sampling procedure. A sun compass can be used, but due to the variable nature of the
266 sun in Shetland, a magnetic compass was deemed more reliable. All of the features sampled were
267 assessed in the field prior to the use of the magnetic compass and it was concluded that no distortion
268 was present (Meng and Noel, 1989; Lange and Murphy, 1990).

269

270 The direction of remanent magnetisation of the samples was measured using a Molspin spinner
271 magnetometer. The stability of this magnetisation was then determined by step-wise alternating
272 field demagnetisation of pilot samples to allow removal of any less stable magnetisations acquired
273 after the firing event, leaving the magnetisation of archaeological interest, known as the
274 characteristic remanent magnetisation (ChRM).

275

276 Pilot samples were selected as they represented the range of characteristics displayed by the
277 assemblage. The demagnetisation data were assessed using methods defined by Tarling and Symons
278 (1967), Kirschvink (1980) and Sagnotti (2013) and principal component analysis (PCA) was used
279 to investigate the linearity of the magnetic vector throughout the demagnetisation process and to
280 select the field used to remove the unstable component of the magnetisation, leaving the
281 magnetisation of archaeological interest. Values of less than 2° were taken as evidence that the plots
282 were acceptably linear between the selected vector, and that the magnetisation was likely to be
283 stable (Linford, 2006). It was noted that a field of 5mT was suitable to remove the less stable
284 component for all of the samples investigated.

285

286 The magnetic directions of the samples collected from a feature were combined to give a mean
287 direction, the precision of which is defined using Fisherian statistics (Fisher, 1953). The alpha-95
288 (α_{95}) value represents a 95% probability that the true direction lies within that cone of confidence
289 around the observed mean direction, and should be less than 5° for dating purposes (Tarling and
290 Dobson, 1995). A value larger than this indicates that the magnetic directions of the samples are
291 scattered and therefore do not all record the same magnetic field, making the material undatable.
292 Outlier samples were statistically defined using the approaches defined by Beck (1983) and
293 McElhinny and McFadden (2000); if the values failed these tests they were statistically classified as
294 lying significantly from the mean and therefore removed from the analysis.

295

296 Context [166] was sampled twice as a portion of the sampled feature lay underneath an unexcavated
297 area of the site. When the area of excavation was extended the remaining part of the feature was
298 exposed and sampled (AM150). The mean directions were shown to be statistically
299 indistinguishable (McFadden and Lowes, 1981) and so they were combined to give a single
300 magnetic direction.

301

302 4.3 *Cryptotephrochronology*

303 Tephrochronology is based on the identification and correlation of tephra layers (Thórarinnsson,
304 1944). The recognition and correlation of cryptotephra deposits (those hidden from view) has
305 extended the precision of tephrochronological correlations to continental scales (Dugmore, 1989;
306 Dugmore et al., 1995a; Swindles et al., 2010; Watson et al., 2017). Calendar dates for the various
307 tephra layers have been obtained through the use of written records (e.g. Thórarinnsson, 1967),
308 correlation to precise timescales such as those provided by ice cores (e.g. Zielinski et al., 1995;
309 1997; Sigl et al., 2015), or complementary dating techniques such as radiocarbon (Dugmore et al.,
310 1995a; 1995b; Wastegård et al., 2008; Swindles et al., 2011). The precision of the associated
311 radiocarbon dates have been greatly improved in recent years through the application of both

312 radiocarbon wiggle-matching and sophisticated age-depth models, including Bayesian approaches,
313 and for some tephra layers this exceeds the available precision associated with a single radiocarbon
314 determination for the same period of time (Hall and Pilcher, 2002; Wastegård et al., 2003).

315

316 Despite the potential of tephrochronology for both chronological and palaeoenvironmental studies,
317 only limited work has been carried out in Shetland (Dugmore 1991; Bennett et al., 1992; Swindles
318 et al., 2013). A number of cryptotephra layers may have been deposited on Shetland during the
319 periods that pre- and post-date the settlements at Underhoull (Dugmore et al., 1995b; Hall and
320 Pilcher, 2002; Swindles et al., 2011). These aid the chronological constraint of the sites, as well as
321 allowing the evidence recorded at Underhoull to be unambiguously linked to sites across the North
322 Atlantic and major paleoclimate archives.

323

324 Monolith samples were extracted from peat faces at the site using box guttering (de Vleeschouwer
325 et al., 2010). A series of three cores were collected from the accumulations of peat under- and over-
326 lying the archaeology in the south-west area of the site (Figures 3 and 4): ‘SF238/239’, ‘SCHO’,
327 and ‘UHM’. The peat cores were stored at 4°C prior to sub-sampling at contiguous 1-cm intervals.
328 Tephra layers in each profile were determined using the conventional ashing and extraction
329 technique (following Swindles et al., 2010). As the samples contained some minerogenic material,
330 LST Fastfloat (2.3–2.5 g cm⁻³) was used to concentrate the shards. The total number of tephra
331 shards within a 1 cm³ sample was counted under light microscopy at 100× magnification. No
332 basaltic shards were encountered in the samples.

333

334 Peat samples from depths of peak shard concentration were selected for subsequent geochemical
335 analysis. Approximately 5cm³ of peat was acid digested (H₂SO₄ and HNO₃) following standard
336 procedures (Dugmore et al., 1992, Pilcher and Hall, 1992) and density separation was undertaken as
337 before. The samples were sieved through a 10µm mesh and washed with deionised water, before

338 being centrifuged to concentrate the tephra shards. The tephra were then mounted onto glass slides,
339 which were polished using 0.25- μ m diamond paste, before being carbon coated (Swindles et al.,
340 2010).

341

342 Geochemical analysis was carried out at the NERC Tephra Analytical Unit at the University of
343 Edinburgh. A CAMECA SX100 electron microprobe with a beam current of 2nA and diameter of
344 5 μ m was used. The microprobe was calibrated using Lipari obsidian and synthetic oxides with X-
345 PHI correction, undertaken on PeakSight version 4.0 software. Energy-dispersive spectroscopy
346 (EDS) using the Princeton Gamma Tech Spirit EDS system was used to aid in the detection of
347 tephra shards. Once a shard was located, the beam was moved to a flat section of the shard
348 (avoiding vesicles) for wavelength-dispersive spectroscopy and all analyses with a value of >95
349 wt% were logged.

350

351 It has been suggested that acid digestion can alter the geochemistry of tephra shards (Blockley et al.,
352 2005). However, the use of this method allows ‘like-with-like’ comparisons with type data which
353 have been prepared in this way (e.g. Dugmore et al., 1992). The case for chemical alteration by acid
354 digestion has also been refuted in subsequent studies (Roland et al., 2015; Watson et al., 2016).
355 Biplots were used to compare our data to those on TephraBase (Newton et al., 2007), with the
356 identified tephra layers summarised in Table 4.

357

358 **4.4 Spheroidal carbonaceous particles**

359 Spheroidal carbonaceous particles (SCPs) are formed following the high-temperature combustion of
360 fossil fuels and are predominately composed of elemental carbon. SCPs are associated with
361 industrial activities that occurred from the mid-19th century onwards, and so the presence of SCPs
362 within a deposit can therefore be used to indicate a post-AD1850 date for the layer (Rose, 1994;

363 Swindles, 2010; Swindles et al., 2015). The SCPs were extracted from the peat cores using the
364 methodology defined by Swindles (2010).

365

366 4.5. Data analysis

367 The chronological information from the Upper House, Underhoull was investigated within a
368 Bayesian framework, which utilises prior information to interrogate and refine the scientific dates
369 (Buck et al., 1991; 1994). All the chronological modelling was undertaken using OxCal v4.3
370 (Bronk Ramsey, 2012). The samples selected have been discussed above, and were recovered from
371 a number of discrete and secure contexts. Primary contexts were prioritised, such as hearth deposits,
372 with short-lived species of charred and waterlogged plant remains preferred so as to avoid the ‘old-
373 wood-effect’. Radiocarbon ages were all calibrated using the international agreed northern
374 hemisphere calibration curve (IntCal13) of Reimer et al. (2013). Archaeomagnetic dates were
375 incorporated into the model as prior probabilities, which were derived from their individual
376 calibrations using the Rendate software and the UK secular variation calibration dataset (Batt et al.,
377 2017). The dates of tephra layers were incorporated as normal probability distributions using a
378 mean and standard deviation with the C_Date parameter in OxCal.

379

380 Inclusion of stratigraphic information can refine the resulting age ranges through the production of
381 posterior density estimates but it is important to note that the resulting age ranges are the result of a
382 statistical model imposed on the data and the interpretation of the stratigraphy within the field. Any
383 new information, such as additional dating evidence or a different model being imposed on the data,
384 will produce different posterior density estimates. The *modelled estimates* are given in *italics* when
385 discussed within the text to differentiate them from the raw calibrated age ranges.

386

387

388

389 **5. Results**

390 The dates produced for the Upper House site have been summarised in Tables 2-4. A summary of
391 each of the results of the dating programme are provided in this section before the chronology of the
392 site is discussed.

393

394 **5.1 ¹⁴C dating**

395 A total of 22 AMS radiocarbon dates were produced for the Upper House, Underhoull, with the
396 majority sampling either the humin or humic acid fractions extracted from the peat (owing to lack
397 of suitable macrofossils). An assessment of the dates obtained from the peat demonstrated that
398 several of the radiocarbon dates (humin fractions) were not in chronological order and appeared to
399 be too old for their stratigraphic position when compared to the tephra dates (Table 2; Figure 4).

400

401 Two radiocarbon dates were produced on the same sample of peat: SUERC-33130 and SUERC-
402 34106 sampled the humic acid fraction and humin fractions respectively, which allowed the dates
403 produced on different fractions of the same sample to be directly compared. It was clear that
404 SUERC-34106 (humin fraction) gave an older age estimate than SUERC-33130 (humic acid
405 fraction; see Table 2), which may be due to the peat formation processes (Brock et al., 2011). The
406 discrepancy noted between the fractions radiocarbon dated may relate to the microscopic charcoal
407 present throughout the peat profiles of the 'SCHO' core (Edwards et al., 2013, Fig 4.6b) and the
408 'UHM' core (Figure 5). The small size of the fragments of charcoal made it impossible to identify
409 the species, which may have provided information about the origin of the material and whether the
410 charcoal related to local species, bog- or drift wood. In situations where wood is scarce, such as the
411 Northern Isles, the use of recycled wood, bog- or drift wood can result in 'old' material becoming
412 incorporated into the archaeological record (Schiffer, 1986). It was therefore also possible that the
413 discrepancy noted in the dates may have resulted from the presence of residual charcoal within the

414 humin fraction. The resulting radiocarbon age would therefore lie between the age of the charcoal
415 present and the peat, rather than giving a date for the accumulation of the peat.

416

417 The presence of the peat accumulations so close to a domestic structure would have provided
418 regular opportunities for burnt material to have become incorporated into the peat, for example,
419 from the burning of bog- or drift wood or ‘old’ peat as a fuel source within the structure itself or in
420 the industrial feature to the north of the site. In addition, burnt material may have been carried to
421 site as hill-wash, or from the land clearance activities to create grazing land for sheep and cattle.

422

423 **5.2 Archaeomagnetic dating**

424 A total of three features were sampled for archaeomagnetic dating, two of which related to hearths
425 located in the S and SW annexes (contexts [166] and [214 respectively) and one to a possible
426 industrial feature (context [093]) to the north of the longhouse. Context [093] butted against the
427 outer wall of the longhouse and was therefore created at a later stage. All of the sampled features
428 recorded remanent magnetisation that was considered stable, with the directions being generally
429 well grouped, as demonstrated by small alpha-95 values (Table 3). An assessment of the samples
430 demonstrated that the magnetisation was stable, but there were a small number of outliers. These
431 samples may have been disturbed in antiquity: all of the anomalous samples were on the edge of the
432 features, the area that is vulnerable to slumping or being trampled on by activity within the
433 structure.

434

435 The calibrated archaeomagnetic dates (Batt et al., 2017) suggest two different phases of activity.
436 The feature sampled in the SW Annexe represented the earliest area of burning sampled at
437 Underhoull, with a date of AD 800–1080 (AM151). The calibrated date is broad due to slow
438 changes in the geomagnetic field between AD 900–1100, limiting the precision available within this
439 period. A radiocarbon date on material interpreted as the occupation deposits associated with the

440 hearth (SUERC-34111), produced a calibrated date of *cal.* AD 1045-1265, which suggests that the
441 latter part of the archaeomagnetic range may better represent the ‘true’ age of the feature, and
442 placing the last use to the 11th century AD at the earliest.

443

444 The feature sampled by AM149/AM150 gave a later date than AM151, AD 1240–1310, suggesting
445 that the activity in the S Annexe continued after the SW Annexe went out of use. This date is
446 supported by a radiocarbon date (SUERC-34108) of *cal.* AD 1045–1260 produced on charred
447 grains recovered from the hearth. A comparison of these two dates suggests that the later part of the
448 radiocarbon range may represent the ‘true’ age of the feature, indicating that the hearth in the S
449 Annexe was in use in the 13th century, but potentially earlier if the full range of the radiocarbon date
450 is considered.

451

452 The archaeomagnetic date for the industrial feature (AM148), AD 1280–1430, indicates that it
453 could have been in use at the same time as the hearth in the S Annexe but it is likely to represent the
454 last area of burning on the site. This is supported by the archaeological evidence which suggests
455 that activity at the Upper House may have continued as late as the early 16th century, to the very end
456 of the Late Norse period and in to the Medieval period.

457

458 **5.3 Tephra and SCPs**

459 Several cryptotephra layers were identified in the peat profiles (Figure 6, Supplementary file 1). The
460 identification of tephra layers, through analysis of major element oxides, is illustrated through
461 biplots shown in Figure 7. The tephras discovered include the Hekla-Selsund (Kebister) tephra in
462 the SCHO profile that has been dated to 1800–1750 *cal.* BC by Wastegård et al. (2008). In addition,
463 the historically dated Hekla-1104 and Hekla-1158 tephtras (Thórarinnsson, 1967) were identified in
464 UHM and Hekla 1158 was identified in SF238-239. A mixed tephra layer was found between 32-42
465 cm in the SCHO profile that could not be assigned to a specific eruption (see Swindles et al., 2013).

466 The Hekla-1158 tephra provides a precise way of correlating the UHM and SF238-239 peat
467 sections, with the Hekla-Selsund tephra dating the start of peat formation at the site. SCPs were
468 found in the uppermost 3 cm of the UHM and SCHO profiles indicating a post 19th-century date.

469

470 *5.4 Underhoull longhouse chronological model*

471 A Bayesian approach was taken to the development of a chronological framework for the peat
472 accumulations and longhouse settlement at Underhoull (Supplementary file 2). In addition to the
473 stratigraphic relationships of the accumulations and the archaeological features, additional
474 information, such as the pollen recorded with the peat deposits, was used to ‘tie’ the three peat
475 sequences together. Edwards et al. (2013) have noted that the sediment accumulation rate may have
476 varied over time. It could have been slower following the accumulation of context [055], and a
477 change in land use (or putative phase of abandonment) between the Iron Age and Norse period, as
478 indicated by the reduction in the grassland and the increase in heath between contexts [041] and
479 [026] (Edwards et al., 2013).

480

481 A single chronological model was constructed that allowed for the evaluation and interpretation of
482 both the longhouse settlement and its temporal relationship with the surrounding peatland. The
483 broad chronological narrative sees a period of peat formation at the site (contexts [055] and [041]),
484 with longhouse walls constructed overtop of [041]. Peat continued to accumulate (context [026]),
485 eventually sealing the walls of the longhouse structure. At some point during the use of the
486 longhouse, a paved surface was laid over context [026], which itself formed over a cleared area of
487 bedrock. The chronological model is given in the form of a simplified Harris matrix (Figure 8),
488 which can be related directly to the OxCal model and the description that follows.

489

490 The chronological model is separated into two main sequences. The first includes the peat
491 formation prior to the longhouse construction (peat sequences SCHO and SF238/239), as well the

492 archaeological activity associated with the longhouse. The second sequence focuses on the
493 beginning of the formation of the upper layers of peat (context [026]) that eventually cover the
494 longhouse and the construction of the paved surface. Tephra deposits from the Hekla eruptions of
495 AD 1104 and AD 1158 occur within context [026].

496

497 The first sequence begins with a date (SUERC-24946) on the humic acid fraction of a sample of
498 peat from the base of context [055]. Within [055] and overlying this peat sample was a layer of
499 tephra from the Hekla-Selsund eruption. The previous wiggle-match date of 1800–1750 cal. BC
500 (Wastegård et al., 2008) is included in this model as a C_Date of 1775 ±25 years BC. Above the
501 tephra, and still within [055], a second radiocarbon result is available (SUERC-33130) on the humic
502 acid fraction of a sample of peat. The two peat samples are separated by only approximately 2 cm
503 within the SCHO sequence. [055] transitions into context [041] and the humic acid fraction was
504 dated (SUERC-33129) on a sample of peat from near the base of the layer in sequence SCHO. A
505 second sample of peat, from sequence SF238/239, had its humic acid fraction dated (SUERC-
506 33131). Although the relative depths would suggest SUERC-33129 is earlier than SUERC-33131,
507 because the two results are from different peat sequences they have been placed in an unordered
508 group. The longhouse was constructed on top of [041], and since it is impossible to know what, if
509 any, peat was removed during the construction, the model separates the pre-longhouse peat
510 sequence from the dating associated with the longhouse activity, while respecting the relative order
511 of the two groups of dates. None of the scientific dates from the structure are stratigraphically
512 related to one another and are modelled as part of a single phase of activity that post-dates the
513 underlying peat. There are five radiocarbon dates (SUERC-24945, -34108, and -34111–3) on
514 individual charred barley grains recovered in various contexts from the main structure, the two
515 annexes, and the yard. Furthermore, there are three archaeomagnetic dates from two hearths
516 (AM149/150 and AM151) associated with the longhouse and an area of burning north of the house

517 (AM148). This portion of the model also includes a cross-reference to a date estimate for the laying
518 of the paved surface derived from the dating in the second sequence.

519

520 The second sequence is derived primarily from peat sequence UHM, which comprises dating
521 evidence from throughout context [026]. Although the humin fractions from the peat in [026] were
522 deemed unreliable due to the potential inclusion of allochthonous carbon, a sample of identifiable
523 *Sphagnum* leaves and stems (Figure 5) was collected and dated (SUERC-24946) from 8 cm above a
524 paving stone. Two tephra dates are available from levels above this radiocarbon sample, from
525 Hekla-1104 and Hekla-1158. It is important to note that the exceptional precision recorded for two
526 of the tephra layers (Hekla-1104 and Hekla-1158) is due to the fact that both of these eruptions
527 occurred within historical time periods and so the specific date of the eruption is known. At some
528 point after [026] began forming, but before the Hekla-1104 eruption, stone paving [029] was laid,
529 which butted against the outer wall face of the longhouse. As stated above, this sequence is linked
530 to the primary longhouse sequence through the dating estimate for the laying of the stone paving.

531

532 The chronological model has good agreement between the different dating techniques and the
533 observed stratigraphic relationships (Amodel=82). Although relatively imprecise, the dating
534 evidence estimates that peat formation began by 2795–1770 *cal. BC* (95% probability; Figure 9;
535 *start: peat formation*), and probably by 2135–1795 *cal. BC* (68% probability). The transition in the
536 peat sequence from [055] to [041], which the pollen indicated shows a sharp change from heath to
537 grazing land, occurred in 675 *cal. BC–cal. AD 235* (95% probability; Figure 9; *transition*
538 *[055]/[041]*), and probably in 495 *cal. BC–cal. AD 130* (68% probability). A considerable amount
539 of time passed between the start of agricultural improvement in the area and the construction of the
540 longhouse, with the model estimating the span covering 670–1625 *years* (95% probability; Figure
541 10; *span: start [041] and longhouse construction*), and probably 825–1425 *years* (68% probability).
542 The Underhoull longhouse was constructed in *cal. AD 805–1050* (95% probability; Figure 9; *start:*

543 *Underhoull longhouse*), and probably in *cal. AD 880–1000* (68% probability). The longhouse was
544 in use for *225–630 years* (95% probability; Figure 10; *span: Underhoull longhouse*), and probably
545 *295–485 years* (68% probability). Activity within the house ended in *cal. AD 1230–1495* (95%
546 probability; Figure 10; *end: Underhoull longhouse*), and probably in *cal. AD 1260–1380* (68%
547 probability).

548

549 The modelling estimates the stone paving was laid in *cal. AD 1035–1105* (95% probability; Figure
550 9; *Paved surface laid*), and probably in *cal. AD 1070–1105* (68% probability). This would indicate
551 that *25–280 years* (95% probability; Figure 10; *span: longhouse construction and paving laid*), and
552 probably *80–205 years* (68% probability), passed between the initial construction of the longhouse
553 and the laying of the paved surface.

554

555 **6. Discussion**

556

557 **6.1 Before the Norse occupation of the site**

558 The dates show that peat began to accumulate in the early second millennium BC, or during the
559 beginning of the Early-Middle Bronze Age. This peat initiation may have been triggered by climate
560 change (e.g. Morris et al., 2018), but recent studies have warned against this interpretation. For
561 example, Lawson et al. (2007) assessed the timing of peat formation in the Faroe Islands, which
562 occurred before any known human settlement of the archipelago, and concluded that no strong
563 evidence could be found to suggest that climate change influenced the timing of peat initiation. Peat
564 formation in the Shetland Isles may be driven by similar processes to those in the Faroe Islands, but
565 despite some similarities in terms of climate and biota, one crucial factor is the very different
566 history of human settlement.

567

568 The dating evidence reported here for a discontinuity in the peat between contexts [055] and [041]
569 is consistent with sharp changes in the pollen stratigraphy reported by Edwards et al. (2013)
570 indicative of a change in the landscape from heath to pasture. This event probably occurred between
571 495 cal. BC–cal. AD 130 (68% probability; Figure 9), placing it firmly within the Iron Age. It is
572 possible that the identified landscape changes identified around Underhoull may be relate to the
573 construction and use of the nearby broch tower.

574

575 **6.2 The construction of the longhouse**

576 We estimate that the longhouse was constructed in cal. AD 880-1000 (68% probability; Figure 9).
577 This compares to the late 7th to late 9th century dates for the establishment of the early Viking
578 occupation of Norwick (Ballin Smith, 2007) and the probable 9th to 10th century earliest phase of
579 the longhouse at Belmont (Larsen et al., 2013). The 9th century dates for these longhouses are
580 contemporaneous with the settlement of Iceland (Schmid et al., 2017) and while this is consistent
581 with the possibility that Shetland could have played an important part in the westward expansion of
582 the Norse, it also highlights the rapid extension of Norse settlement westwards from Norway in the
583 9th -10th centuries.

584

585 **6.3 The occupation of the structure**

586 The end of the longhouse occupation at Underhoull occurred between cal. AD 1260-1380 (68%
587 probability; Figure 9). These dates also compare well with those produced for other longhouse sites
588 in Unst, where the primary occupations of the longhouses at Hamar and Belmont were placed to the
589 11th-13th centuries AD (Larsen et al., 2013; Bond et al., 2013). However, it is important to note that
590 the chronological evidence from Hamar and Belmont has not yet been fully investigated and so
591 greater resolution may be available in the future.

592

593 The dating evidence and modelled estimates produced from the Upper House structure appear to fit
594 within a developing pattern in Shetland and the wider region of Atlantic Scotland, for extensive
595 settlement late in 9th and through the 10th centuries AD. Conventionally, sites such as the Upper
596 House, Underhoull and Hamar have been interpreted as representing short-lived, single-phase
597 settlements based on a survey of the visible structural remains and surface features. However, now
598 that a number of these structures been excavated, there is evidence the structures underwent several
599 phases of use and modification over a prolonged time period. This included the division of the
600 structures into separate rooms, the addition of annexes, and use through to the end of the Late Norse
601 period (Bond et al., 2013; Larsen et al., 2013). Collectively, evidence produced from the Upper
602 House, Underhoull combined with data from recently excavated sites of Hamar and Belmont
603 indicates that established ideas about the nature and use of such sites needs reassessment, in the
604 light of longer, more complex and nuanced stories of settlement.

605

606 **6.4. The abandonment of the structure and peat development**

607 Following the production of posterior density estimates, dates associated with the use of the
608 structure, place occupation within the *cal.* 10th-13th centuries AD. The youngest features recorded
609 on the site relate to a possible industrial area associated with large quantities of fuel-ash slag and an
610 area of burning (context [093]). An archaeomagnetic date of AD 1280-1430 (AM148) was
611 produced on the area of burning. This suggests that activities at the site continued through the 13th-
612 15th centuries, placing them between the very end of the Late Norse period and into the Medieval
613 period. This correlates well with other examples of other well-dated Norse settlements in the
614 Northern and Western Isles of Scotland, such as Bornais (Sharples, 2005), Cille Pheadair (Sharples
615 et al., 2004), and Pool (Hunter, 2007). Unfortunately, no material suitable for dating was recovered
616 from the final phase of occupation at Hamar (Phase 5), although an archaeomagnetic date of AD
617 1100-1330 (AM154) produced for a hearth assigned to the Phase 3 occupation can be used to
618 provide a *terminus post quem* for the final phase of activity (Bond et al., 2013). The dating evidence

619 from these sites may place their abandonment into a period of climate change, increased winter
620 storminess (Dugmore et al., 2009), and “famine, war, and plague” that affected Atlantic Europe
621 from the 14th century (McGovern, 2000; Dugmore et al., 2007). It is unclear at present why the
622 Upper House site was abandoned and whether this related to environmental or economic factors that
623 resulted in a change in the activities carried out in the area or a decline in the status of the site.

624

625 The excavation of the Upper House, Underhoull shows that the occupants built the longhouse in an
626 area where peat was already accumulating, which raises the possibility that continued peat growth
627 contributed to the abandonment of the site. The dates obtained for the construction of the paved
628 surface over the peat (context [029]), could be interpreted as an attempt by the occupants to manage
629 the site and maintain a dry and stable area around the longhouse despite the close proximity to the
630 peat. A modelled estimate of *cal. AD 1070-1105* (68% probability; Figure 9) obtained for the paved
631 surface, places its construction in the 11th century AD at the earliest, but possibly as late as the early
632 12th century. When this is compared to the estimates obtained for the construction of the longhouse,
633 it is possible to argue that the features were contemporary as the modelled estimates overlap, but it
634 is also possible that the paving related to a later phase of activity. This uncertainty illustrates the
635 challenges of site interpretation, even in the context of high resolution, multi-method chronology.

636

637 When the occupation of the structure is compared to the dates of peat accumulation two of the
638 deposits sampled from within the structure (SUERC-24945 and SUERC-34113) and the possible
639 industrial feature (AM148) are found to be younger than the Hekla-1158 tephra recorded in the peat
640 located 7 cm above the paved surface to the south of the structure. Two of these dates (SUERC-
641 24945 and AM148) sampled primary, *in situ* contexts and indicate that the occupation of the
642 longhouse and the activity on the site continued even when the peat had encroached on the structure
643 and paved surface. This was unexpected and suggests that the abandonment of the site cannot be
644 attributed solely to the growth of peat on the site. This illustrates how well-constrained chronologies

645 demand more nuanced explanations for settlement change (e.g. Dugmore et al., 2012) than the
646 mono-causal drivers that are often invoked.

647

648 7. Conclusions

649 The development of the chronology for the Upper House site at Underhoull demonstrates the
650 strength of using a multi-method approach including cryptotephrochronology; the different dating
651 techniques sampled different materials and targeted different dated events, which provided a more
652 complete assessment of the chronology. It was noted that the dates produced on the peat humin
653 fraction appeared to sample residual material. It can be concluded that the anthropogenic activity in
654 the area adjacent to the peat has encouraged the incorporation of residual material, such as 'old'
655 wood or peat into the peat following their use as a fuel source on the site. This has complicated the
656 determination of the chronology and acts as a warning to other studies that aim to produce dates on
657 the humin fraction of peat sampled so close to settlement/activity sites. Hand-picked plant
658 macrofossils (e.g. *Sphagnum* remains), when present, are best for reliable dates from peats from
659 archaeological contexts. We found that ^{14}C dates on charred barley grains correlate well with
660 archaeomagnetic dates on hearths as both reflect the latest use of the feature.

661

662 The accurate and precise dating of the Upper House site, Underhoull required the detailed
663 consideration of the contexts, the stratigraphy, and the scientific dates. The integration of specialists
664 (dating and environmental) both in the planning stages of the project, and in the field, aided the
665 development of the chronology. In addition, the assessment of dates in sequence further enhanced
666 the development of a robust chronology, combining the strengths of each method, compensating for
667 their weaknesses and identifying any anomalous dates. One of the greatest advantages of this
668 approach was the ability to produce modelled estimates for key events in the life of the site that
669 could not be directly dated, such as the construction of the longhouse and the truncation events
670 recorded within the peat that were indicative of the rearrangement of the landscape. The best results

671 were achieved when several dates from a sequence could be assessed, allowing the internal
672 consistency of the dates from each context to be determined as well as using the stratigraphic
673 relationships of the samples to refine the age ranges further.

674

675 The construction of the longhouse c. *cal. AD 880-1000* lies between the very first phases of the
676 settlement of Iceland and the settlement of Greenland, indicating that the Norse were consolidating
677 settlement in the eastern North Atlantic region while simultaneously extending westward. The
678 abandonment of the site echoes the demise of Norse settlement in Greenland (e.g. Dugmore et al.,
679 2012). This reinforces the idea that settlement contraction was not happening simply at the margins
680 of European settlement, but instead was more widespread, for example in Atlantic Scotland and the
681 more-marginal areas of Iceland (Vésteinsson et al., 2014). Multi-method chronologies combined in
682 Bayesian analysis offer exciting opportunities to realise the potential of archaeology as Distributed
683 Long-term Observing Networks of the Past (DONOP - Hambrecht et al., 2018), to tackle Grand
684 Challenge agendas in archaeology (Kintigh et al., 2014), and also provide detailed and extensive
685 data on the changing lived environment of wide relevance in Quaternary science.

686

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702

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979 **Figure captions:**

980 Figure 1: Location map of Shetland and the island of Unst, highlighting the Norse sites excavated to
981 date. The Upper House site, Underhoull is located at 60.72°N, 0.95°W.

982

983 Figure 2: (a) The key archaeological sites located in the Westing area of Unst; (b) the Norse
984 longhouse excavated at Underhoull as part of the Viking Unst Project, referred to as the ‘Upper
985 House’.

986

987 Figure 3: Extent of peat accumulations recorded adjacent to the Upper House site, Underhoull.

988

989 Figure 4: The relative positions of the three cores used to sample the peat. The position of the
990 material sampled for dating has been highlighted.

991

992 Figure 5: Summary of the concentration of charcoal present within the ‘UHM’ core following
993 extraction using a 63 µm sieve. The presence of *Sphagnum* remains in the UHM core is also shown.

994

995 Figure 6: Tephrostratigraphy of the three peat profiles (number of tephra shards per cm³). The
996 horizon representing the first appearance of SCPs (dated to c. AD 1850 or later) are also shown

997

998 Figure 7: Tephra geochemistry biplots. Type analyses from tephabase (Newton et al., 2007) are
999 shown for comparison.

1000

1001 Figure 8: Simplified Harris matrix for the Upper House at Underhoull.

1002

1003 Figure 9. The chronological model for the Upper House at Underhoull.

1004

1005 Figure 10. Timing of key events associated with the Upper House at Underhoull.

1006

1007 **Table captions:**

1008 Table 1: The definition of the types of deposits recorded at the Upper House, Underhoull using the
1009 methodology defined by Schiffer (1987) and Dockrill et al. (2006).

1010

1011 Table 2: Summary of the AMS radiocarbon dates, calibrated using IntCal13 (Reimer et al., 2013).

1012

1013 Table 3: Summary of the archaeomagnetic dates produced from the Upper House, Underhoull. All
1014 of the sampled deposits represented primary deposits. The mean directions are the characteristic
1015 remanent magnetisation directions at the site and have been calibrated using ARCH-UK.1 (Batt et
1016 al., 2017).

1017

1018 Table 4: Summary of the tephra horizons recovered from the peat.

1019

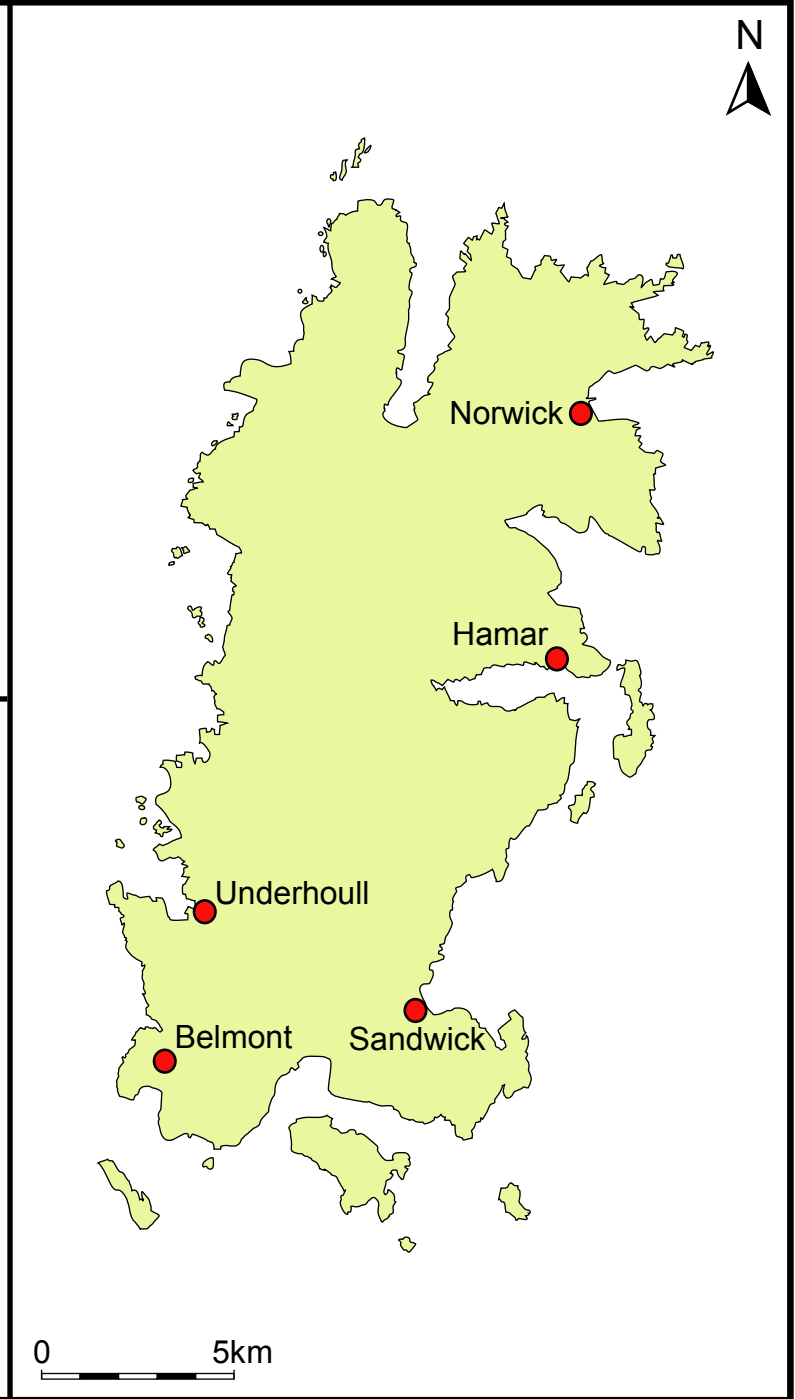
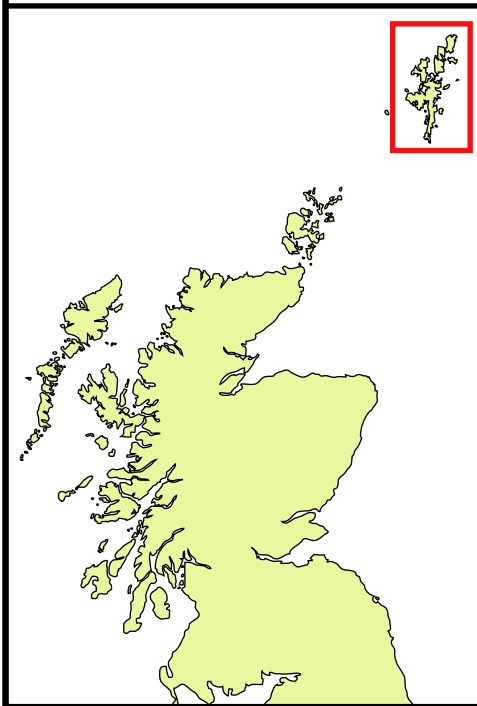
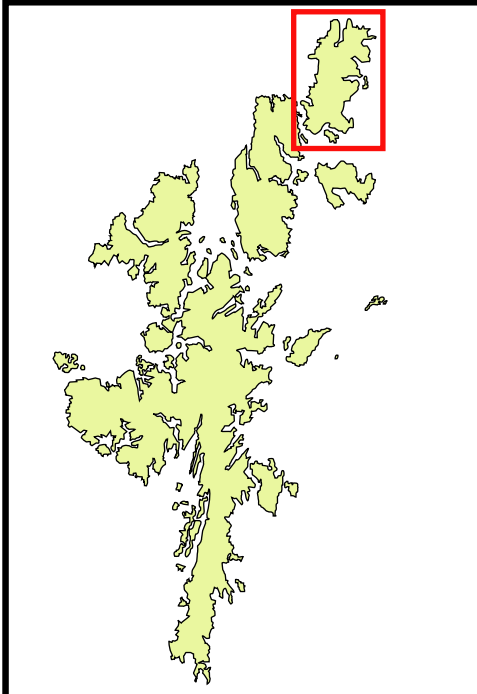
1020 **Supplementary files:**

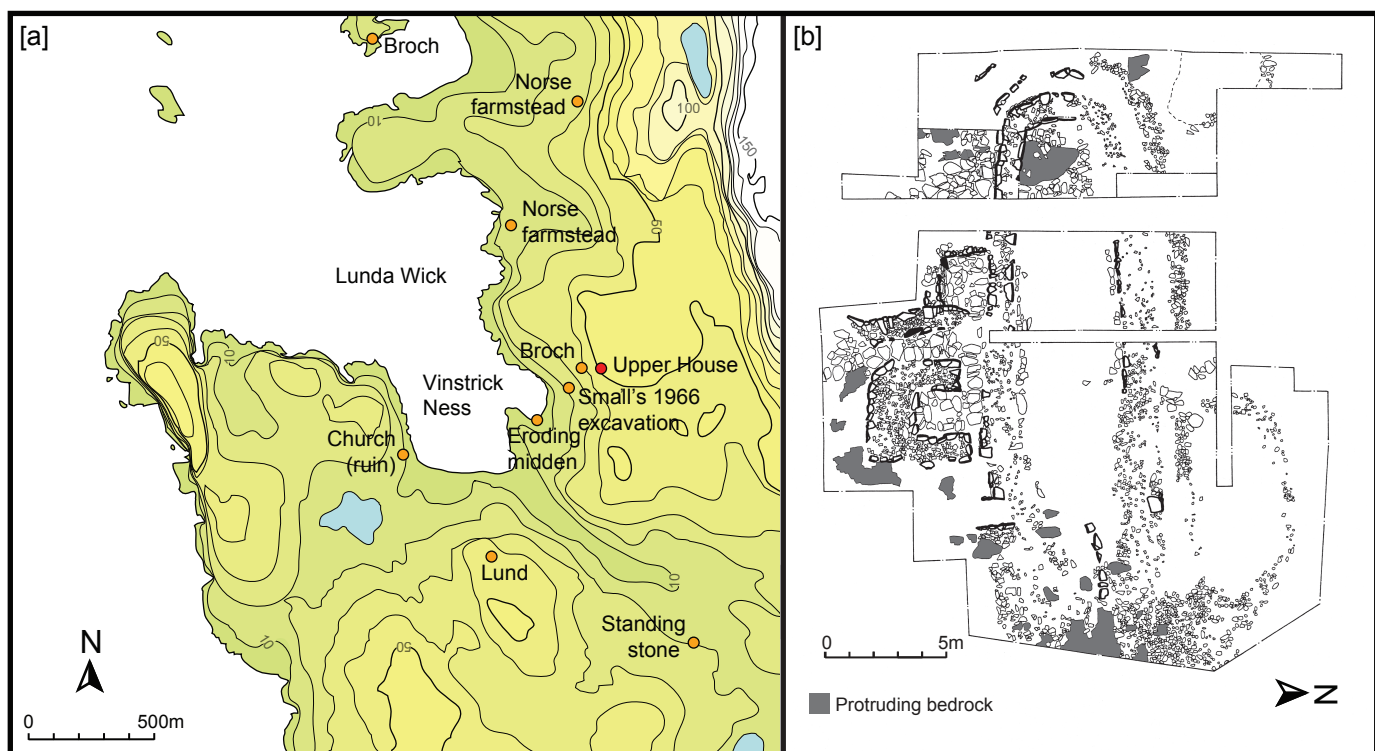
1021 Supplementary file 1: Tephra geochemical data.

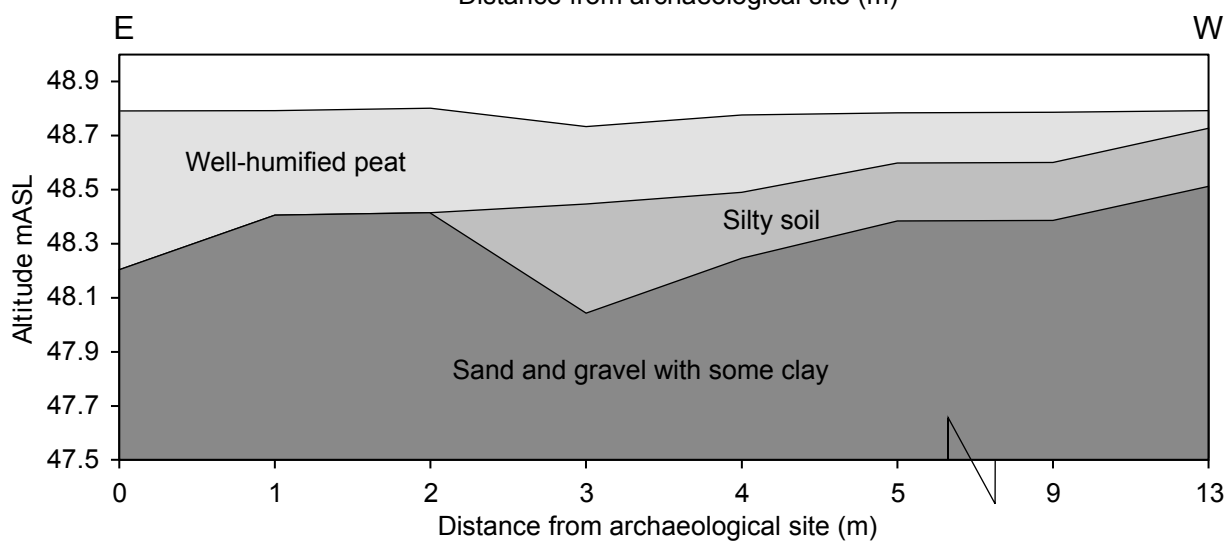
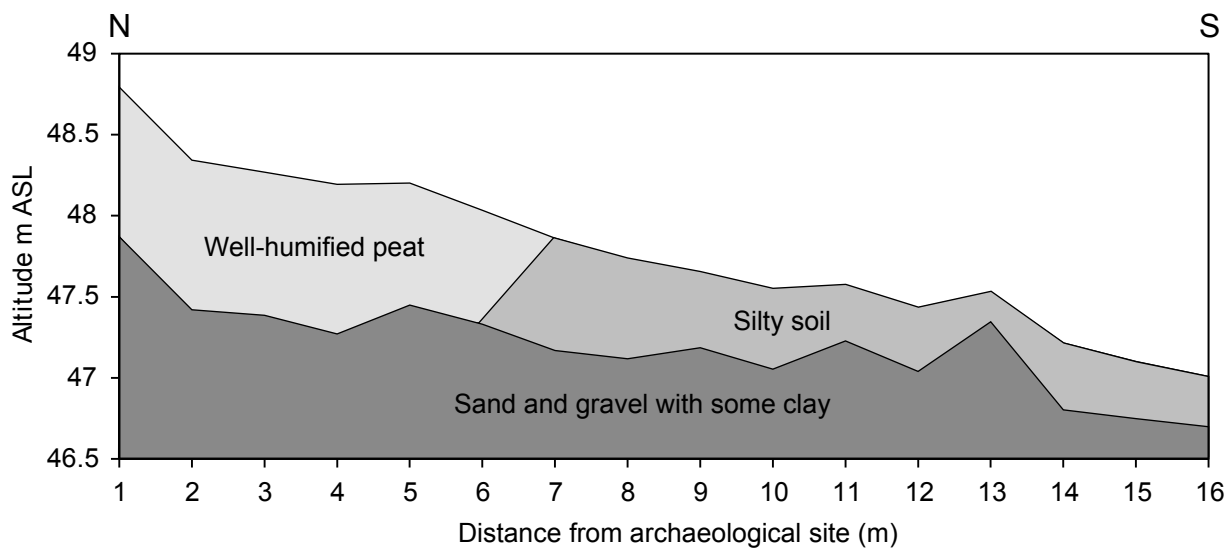
1022 Supplementary file 2: Bayesian model code and prior files for the archaeomagnetic dates.

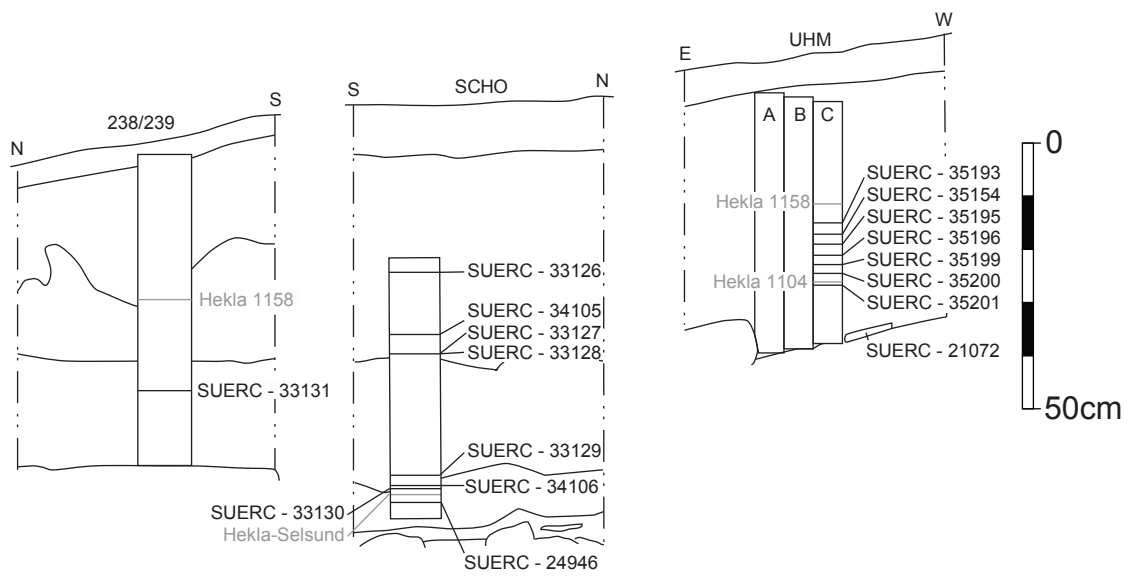
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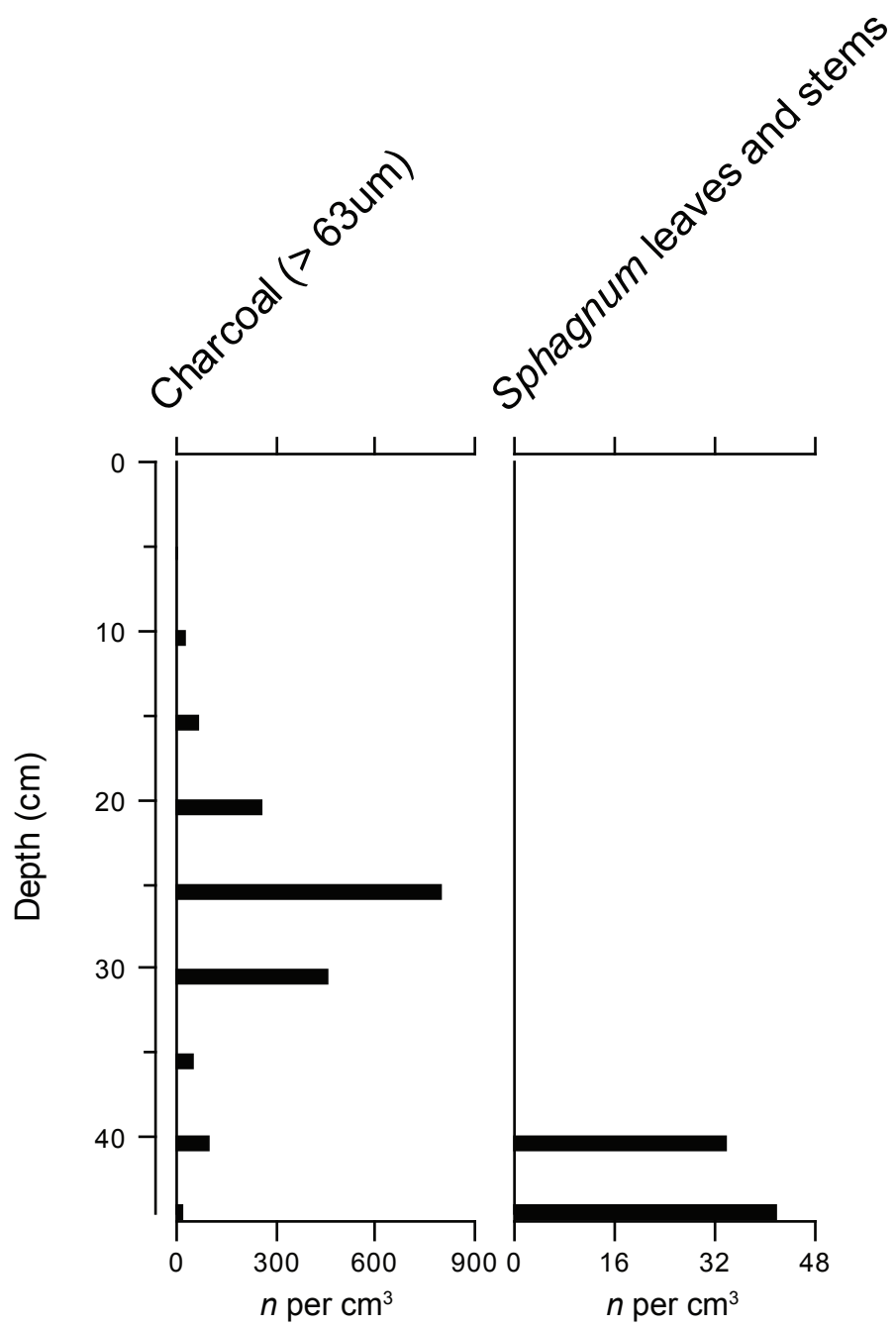
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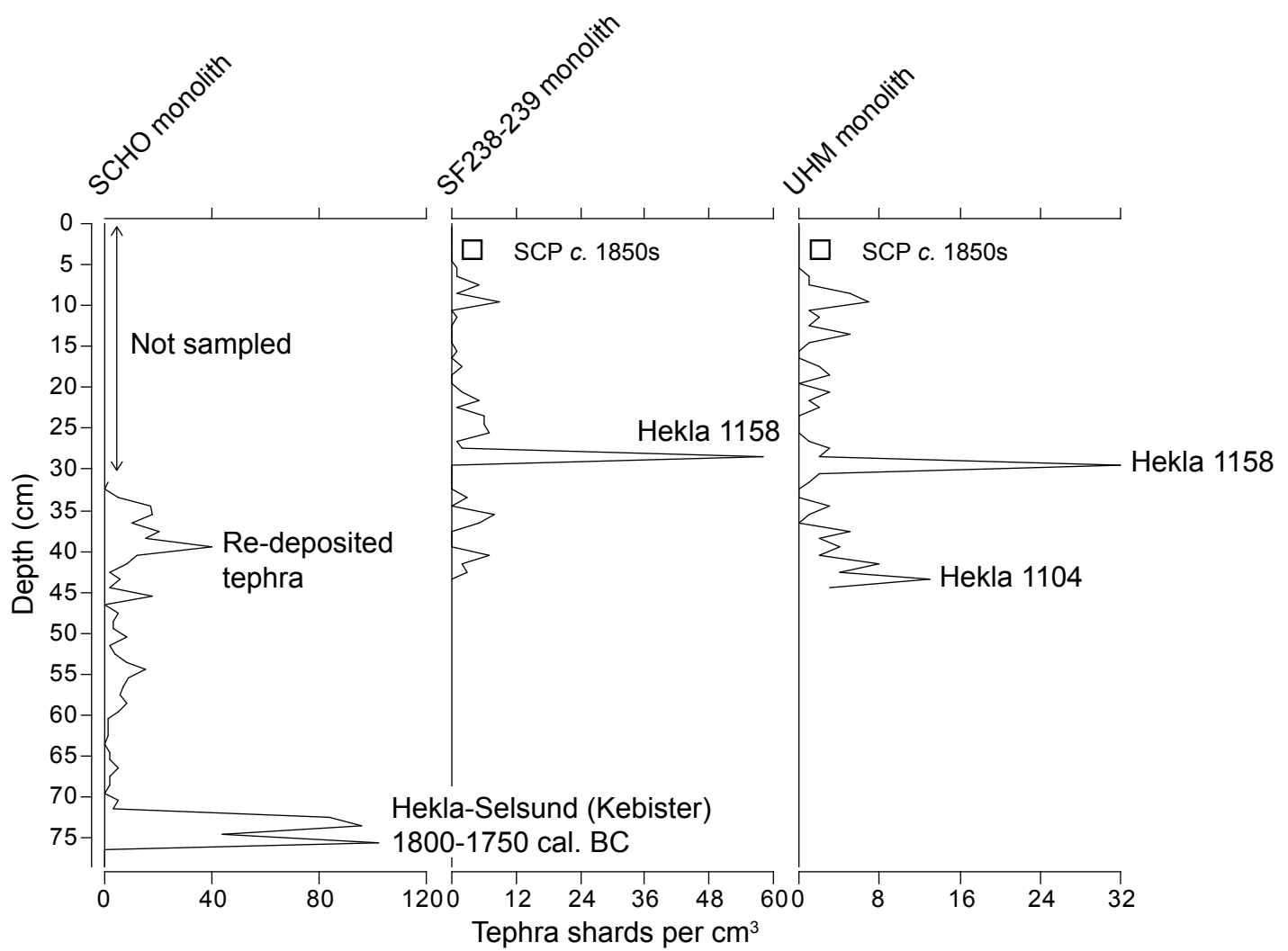


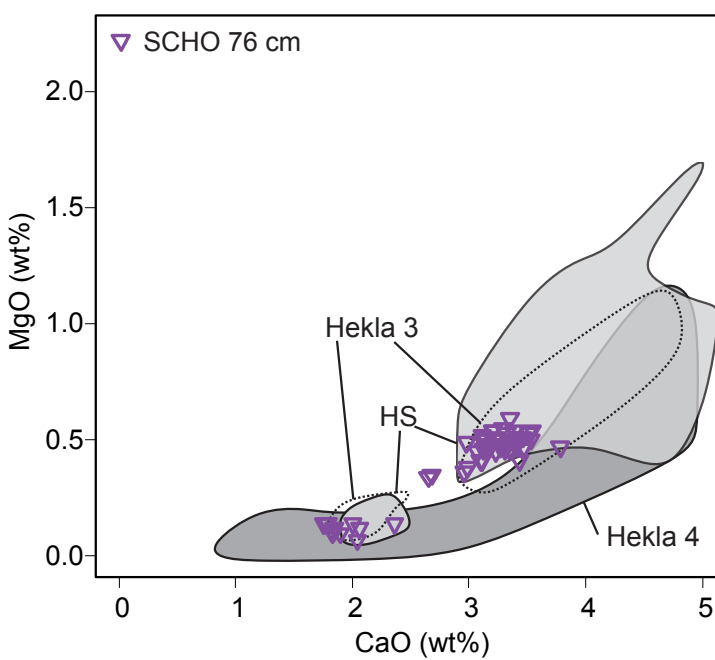
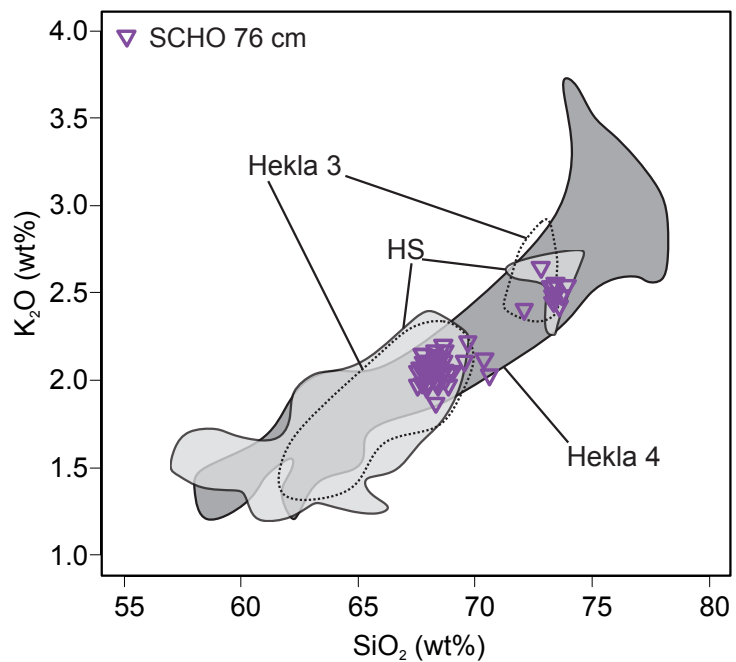
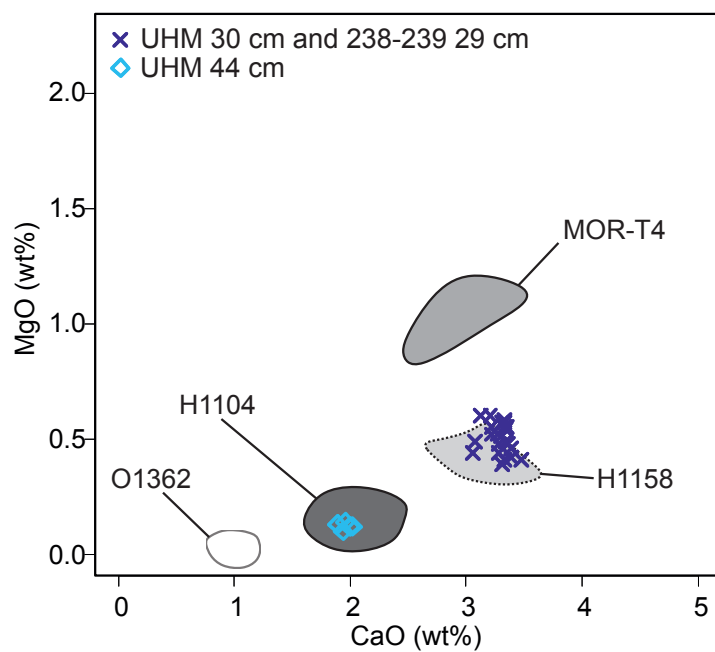
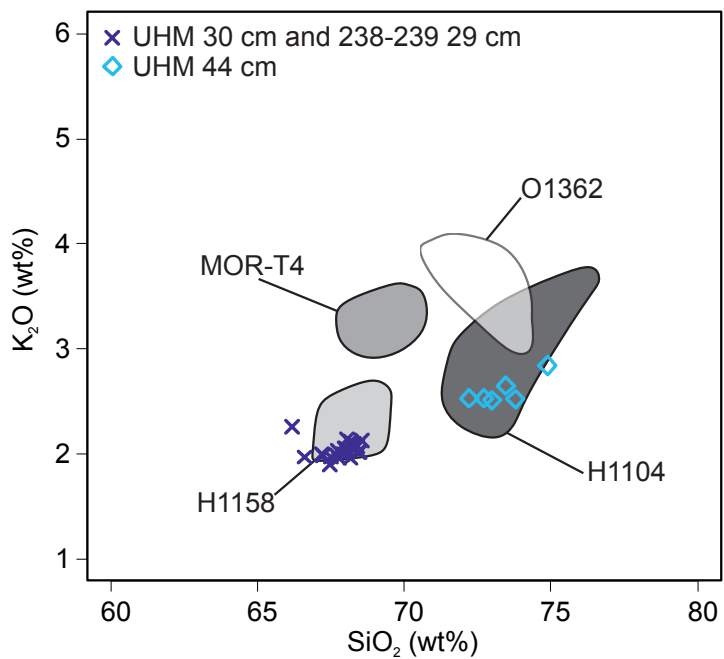


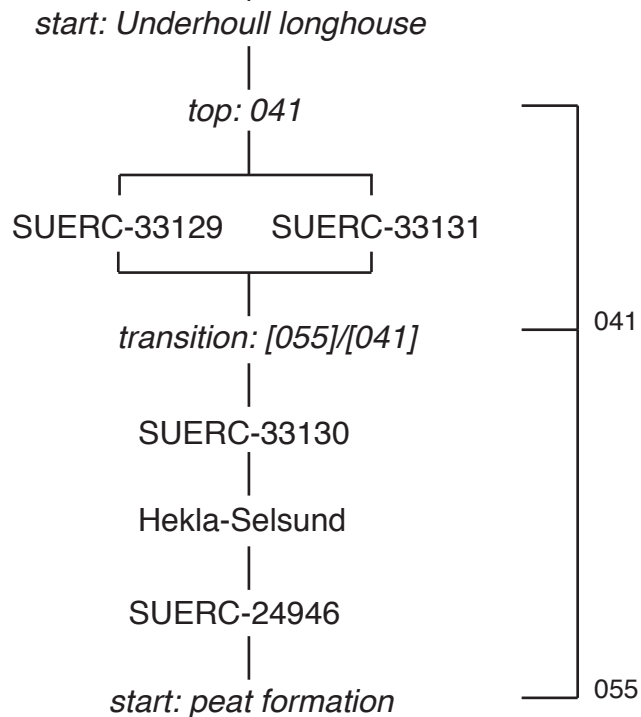
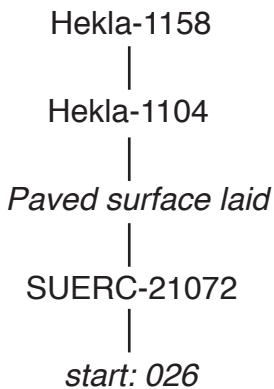
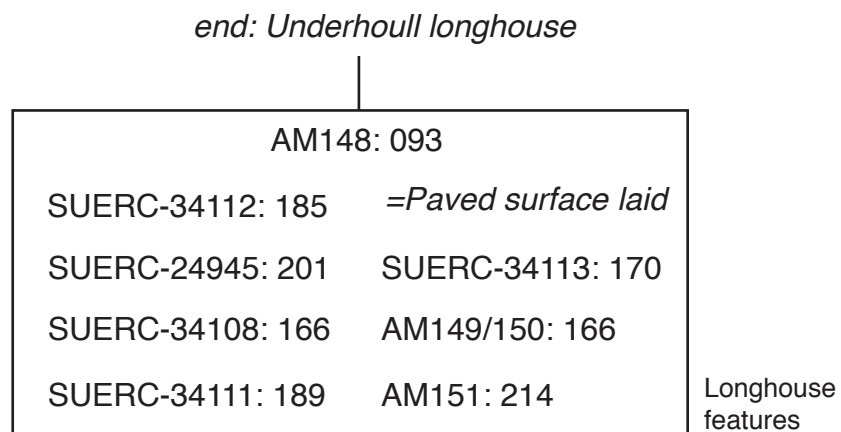


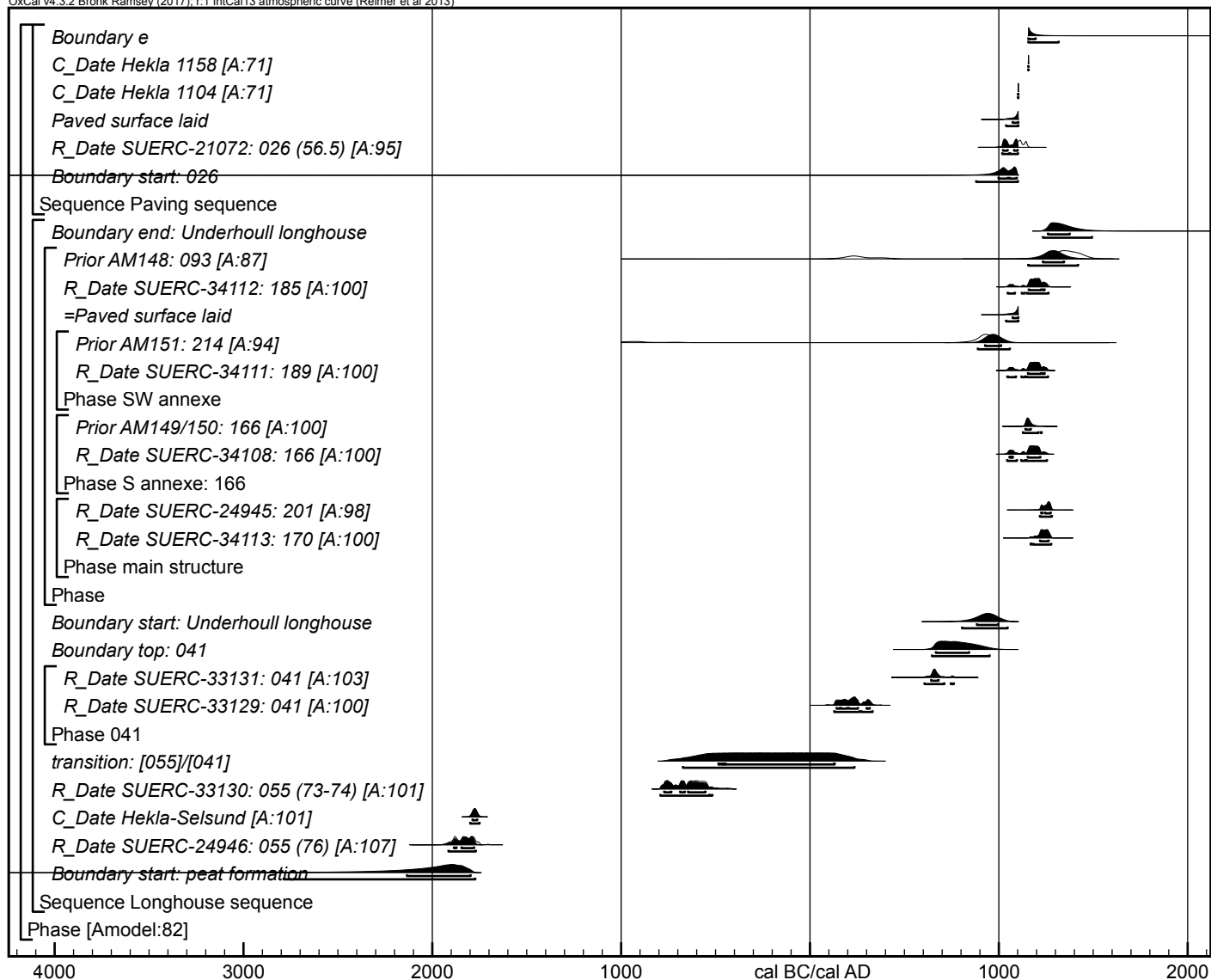




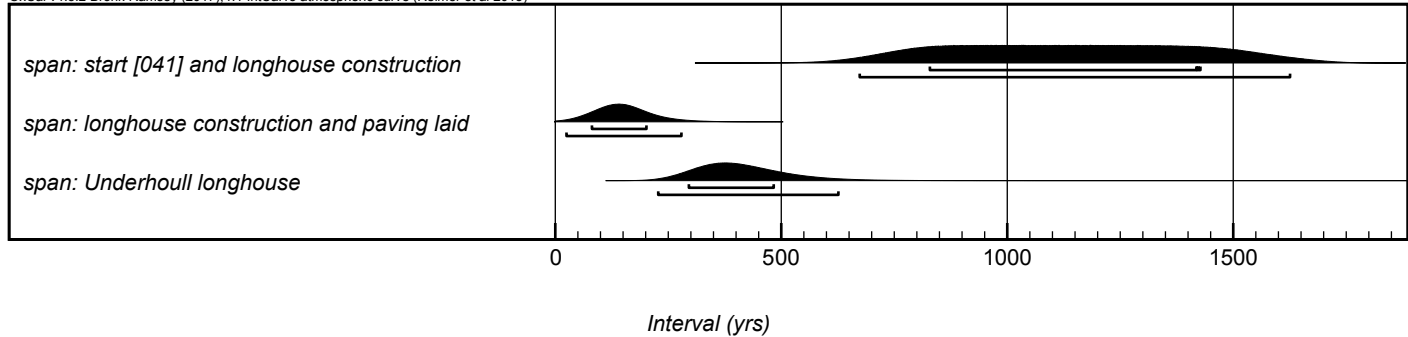








Modelled date (cal BC/cal AD)



Deposit type	Min. number of times the material has been moved	Description and key features for identification	Example	Reference
Primary	None	An <i>in situ</i> deposit	Hearth deposits, dedicatory deposits, Microrefuse trodden into a floor	Schiffer, 1987, p.58
Secondary	Once	The boundaries separating deposits would be clear and distinct	A midden, the material raked out from a hearth	Schiffer, 1987, p.58; Dockrill et al., 2006
Tertiary	Twice	The deposits would be homogenised. The boundaries separating deposits may be merging and diffuse	The use of a midden deposits to level an area	Dockrill et al., 2006

	Context	Description	Lab. Ref. SUERC-	Material	Monolith	Depth from surface (cm)	Depositional context	Uncalibrated <i>Years BP</i>	Calibrated <i>95% confidence</i>	$\delta^{13}\text{C}$ ‰
Deposits associated with the structure	201	Dark red ashy material running down the edge of the interior, interpreted as a possible hearth	24945	Charred barley			Secondary	765±30	AD1220-1280	-26.5
	166	Orange/red hard baked ash hearth within S annexe	34108	Charred barley			Primary	866±35	AD1045-1260	-24.8
	189	Occupation deposit in the SW annexe	34111	Charred barley			Secondary	856±37	AD1045-1265	-23.0
	185	Occupation deposit in the centre of the structure	34112	Charred barley			Secondary	849±37	AD1045-1265	-23.7
	170	Steatite and charcoal rich deposit in the yard area to the N of the structure	34113	Charred barley			Secondary/Tertiary	792±35	AD1175-1280	-24.0
Peat	026	Purple/black peat overlying the bedrock	35193	Humin fraction	UHM	32.5	Primary	1769±37	AD135-380	-28.6
			35154	Humin fraction	UHM	34.5	Primary	1434±35	AD565-660	-28.6
			35195	Humin fraction	UHM	36.5	Primary	1578±35	AD410-560	-29.0
			35196	Humin fraction	UHM	38.5	Primary	2314±37	510-210BC	-29.3
			35199	Humin fraction	UHM	40.5	Primary	2158±37	360-60BC	-30.1
			35200	Humin fraction	UHM	42.5	Primary	1558±37	AD420-580	-29.5

			35201	Humin fraction	UHM	44.5	Primary	1622±35	AD345-540	-29.0
			21072	Sphagnum leaves & stems	UHM	56.5	Primary	970±30	AD1015-1155	-27.4
	041	Brown peat sealed by flagstones [029] and peat [026]	33131	Humic acid	SF239	45-46	Primary-Tertiary	1358±37	AD610-770	-29.0
	026	Purple/black peat overlying the bedrock	33126	Humic acid	SCO	31-32	Primary-Tertiary	1688±37	AD255-425	-28.9
			34105	Humin fraction	SCO	44-45	Primary	1905±37	AD20-220	-29.8
			33127	Humic acid	SCO	44-45	Primary-Tertiary	1708±37	AD250-410	-29.4
			33128	Humic acid	SCO	47-48	Primary-Tertiary	1604±37	AD385-550	-29.3
	041	Brown peat sealed by flagstones [029] and peat [026]	33129	Humic acid	SCO	71-72	Primary-Tertiary	1799±35	AD130-335	-29.4
	055	Dark peaty material sealed by [041]	33130	Humic acid	SCO	73-74	Primary-Tertiary	2504±37	790-425BC	-29.3
			34106	Humin fraction	SCO	73-74	Primary	2774±37	1010-830BC	-30.1
			24946	Humic acid	SCO	76	Primary-Tertiary	3515±30	1920-1750BC	-29.0

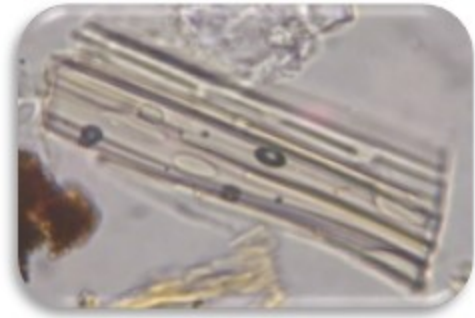
Context	Description	Lab. Ref. (Bradford)	Number of samples	Mean Declination <i>Degrees</i>	Mean Inclination <i>Degrees</i>	Alpha-95 <i>Degrees</i>	Precision parameter	Stability index	Calibrated age range 95% confidence
214	Orange/red hard baked ash hearth material within SW annexe	AM151	14	28.1	70.4	4.1	115.5	Stable	AD800-1080
166	Orange/red hard baked ash hearth within S annexe	AM149 & AM150	51 (26 + 25)	10.2	58.1	1.9	122.7	Stable-Very stable	AD1240-1310
093	Large area of burning associated with a possible industrial activity	AM148	20	-8.5	59.5	4.8	63.5	Stable	AD1280-1430

Context	Description	Core	Depth from surface <i>cm</i>	Volcano	Date
026	Purple/black peat overlying the bedrock	UHM	29.5	Hekla	January 19 th AD1158
		239	28.5	Hekla	January 19 th AD1158
		UHM	42.5	Hekla	October AD1104
		SCO	74.5	Hekla (Selsund)	1600-1650 cal. BC
055	Dark peaty material sealed by [041]				

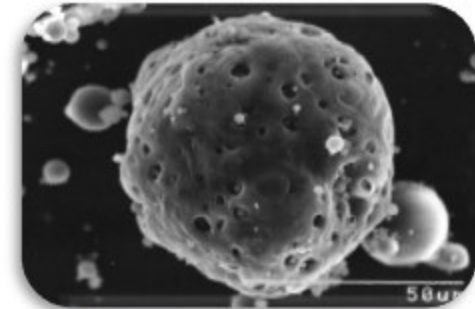
Underhoull longhouse Shetland Isles, UK



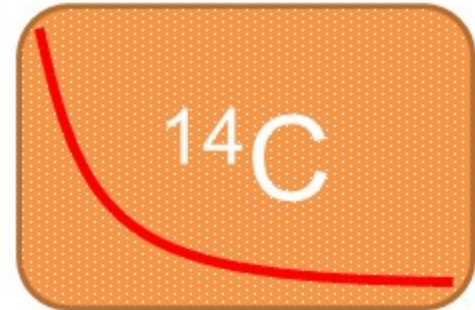
Peat sampling



Tephra



SCPs



Radiocarbon



Archaeo-
magnetism

1. We investigate the chronology of a Norse house in the Shetland Isles, UK.
2. A multi-method approach including ^{14}C , tephra and archaeomagnetic dating is used.
3. The results have implications for Norse expansion across the North Atlantic.